Problems of 3D Scanning and Scanned Data Processing

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Abstrakt
3D skenování je významnou metodou reverzního inženýrství, která se prosazuje v různých oborech, ale zejména v metrologii. Existuje řada zařízení, která dokážou nasnímat tvar skenovaného předmětu a převést jej do digitální podoby. Tento převod však bývá spojen s různými problémy, neboť výstupní data musí vyhovět řadě aplikací, jejichž požadavky jsou rozdílné a někdy i protichůdné. Následující příspěvek má přiblížit problematiku skenování a zpracování dat podle požadavků na jejich konkrétní využití.

3D laser scanning is a progressive method of reverse engineering. It makes possible to completely capture shape of any object. Software for processing of captured data can export the data in to many formats, supported by today's CAD/CAM systems.
Digitizing is usually linked to specific tasks, because output data must meet the needs of various applications, whose requirements are different and sometimes opposite. Following text is focused on questions of scanning and data processing according to needs of specific usage.

Key words
3D scanning, coordinate measuring machine, digitisation of surface, point cloud, reverse engineering.

1. Introduction

3D laser scanning is a progressive method of reverse engineering. It makes possible to capture form of any object. Digitizing of 3D shape using laser scanning head is a new method, which is being applied especially in metrology, various simulation calculations, reverse engineering and not least in design and art.
There are many different types of devices, which is used for 3D digitizing. The devices can be based on tactile principle, on optical principle and some of them even use computer tomography, but the most common for digitization are devices based on laser technology. In contrast with other methods of 3D digitizing, laser scanning devices are quick, have unlimited working volume and are precise enough for most non-industrial application.
This paper describes using of laser scanning methods from industrial point of view, where scanners are usually connected to CNC coordinate measuring machine and point clouds are used for part inspection, reverse engineering and various types of FEM simulation. In contrast to advertising information from scanner developers, this paper describes problems related to scanning, data evaluation and gives certain recommendation, how to acquire good scanned data. The recommendations are based on author's experience from some tests, which he had performed with the laser scanner.

2. Characteristics of 3D laser scanning

Laser scanner emits red beam, which is swept by oscillating reflector. The beam, when falls to the scanned surface, looks like red line or curve. The curve represents optical section through the surface. This section is captured by CCD camera with 20 – 80 frames per second (depends on type of laser scanner). During data capturing, laser scanner is moving over scanned surface and sending frames to further processing to computer. Images from the camera are transformed in to "point cloud", which is consisted from rows containing single scanned points. Normal point cloud can consist from hundreds of thousands points. There is possible to set the density of point cloud before scanning. Density setting depends on quality of information that we want to get from scan. The density can be set by entering distance between single points in the row and by entering distance between single rows.

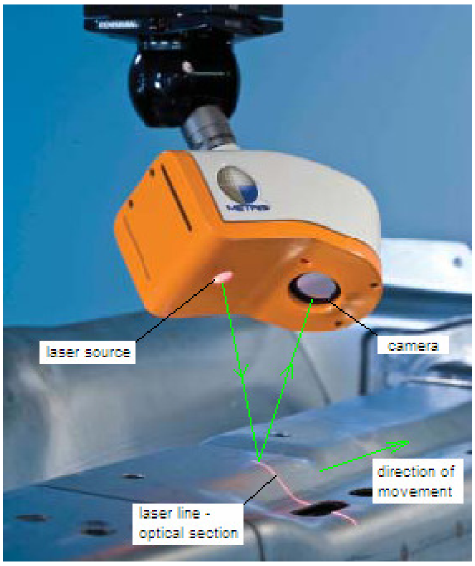

Fig. 1. *Principle of laser scanning head [5].*

Today's processing of scanned data can be automated in so far, as is possible to get data about complete 3D shape of every piece from whole production batch. Actually there exists some software, which can generate polygonal mesh automatically in real time. It is used especially with handheld scanners and applications, where a high accuracy of measurement is not required (e.g. inspection of castings). It is one way, how to quickly and easily digitize the shape of some object.

In certain cases is necessary to have full control over processing of scanned data. Usually it is when CAD model is reconstructed from damaged moulds and dies. It is very typical application, where is necessary to separate small details from large faces, differentiate between real holes and missing data in polygonal mesh or rebuild straight edges from real filleted edges.

A human intervention in to data processing is very essential in this case. Human operator optimizes work with the data so that it can reach the best quality as possible to meet the needs of specific application, e.g. CNC machining or dimensional inspection of very accurate parts.

3. Problems of scan data optimisation

3.1 Quality of scanned data

Quality of scanned data is dependent on the density of point cloud. The quality is primarily affected by the intensity of the laser line, which is projected on scanned surface. In addition to this, final intensity of laser line received by camera is dependent on character of scanned surface, such as reflectivity, transparency, roughness, material and colour.

Primary output from the laser scanner is so called point cloud. It is a set of scanned points, which represents a part of surface or whole surface of scanned solid. It is input format for further processing of scanned data. We can split the data processing into a few steps, according to how we want the data use. The steps are:

- subtracting, joining and filtering partial point clouds in to one
-comparing the point cloud against CAD model of scanned solid and/or detecting and inspection of geometrical objects
- creating polygonal mesh
- replacing of polygonal mesh by smooth curves and faces (NURBS)

The first step leads to adaptation of raw scanned data to further work. It is very common, that we are not able to scan one face in one run of the scanner over the object. It is obvious, that more than one run must be done, so that sub point clouds partially covers each other without any gaps. To scan the part without gaps leads to generating of overlap error. Its magnitude is dependent on uncertainty of the scanning head.
Usually there are some objects we do not want to have in final point cloud (e.g. table of CMM, parts of a fixture etc.). Undesirable parts of point cloud can be simply selected and deleted in point cloud software. But when we want to eliminate overlap error, we cannot do it simply by deleting of overlapped points.
Overlapped points seem to be identical in graphics of software, but in fact they are moved towards the others. They can be moved up to the value of the scanning head accuracy. This negatively affects the quality of the created polygon mesh.
The overlap error can be cleared off by a function that subtracts those points from the scanned cloud that are out the specified tolerance field. It is possible to blend the passage between single (subtracted) point cloud parts. This is necessary at those point clouds that are intended for CNC machining. If the blend is not made there will be steps or jumps at the final machined surface according to the position of the subtracted point cloud part.

3.2. Scanning setup

As mentioned before, the scanning is done with a specific frequency and this affects the final density of the point cloud. Scanned data are usually ordered in rows that consist from separate points. Therefore is laser scanner sometimes called the line scanner. We can control the pitch between the points in one line (hardware filtering) and the pitch between the lines. The pitch between lines is controlled by the CCD camera frequency. Therefore it is connected with the scanner movement speed above the scanned surface. The faster is the movement the bigger is the distance between lines.
The choice of the correct pitch is dependent on the curvature and complexity of the scanned surface. Some tests were performed [4] concerning quality of STL surface in dependency on pitch between single points of point cloud. From the tests is resulting some recommendation for pitch settings:
for flat surfaces and surfaces with a constant curvature a bigger pitch is useful (from 1 to 5 mm) For rugged and shaped surface or for better edge recognition a lower pitch is recommended (approx. 0,05 – 0,9 mm). A criterion of point cloud complexity was a number of holes in scanned mesh.
Point cloud density optimization has several benefits. It can improve the speed of the scanning at lower point cloud density. A lower density produces less data and improves the data filtering speed, so that work with them is faster.

3.3. Data filtering

Data filtering is used to specify the final point cloud density. Final density directly affects the polygon mesh complexity that is used by simulation software or CAD/CAM software. Type

and parameters of the filter are selected according to following purpose. For metrological purpose especially for the comparison between the scanned data and the CAD model an unfiltered or just simply filtered data can be used. A simple filter just removes points that are closer to each other than the specified distance.
If the data are intended for reverse CAD model creation a more complicated filter must be used. Points are filtered according to the curvature in the specific point. Filter removes more points in places with small curvature and keeps points at places with high curvature (Fig.2). It helps to catch edges and rugged surfaces but to keep a low data amount for them. For the purpose of simulations using a FEM method both filters are applied. Simulation application, requires a low amount of points, but keeping the shape as close to the original as possible. The main purpose is saving time and computing power. Although modern computers are powerful they are still not able to process in acceptable time so complicated data as it can be provided by the laser scanner.

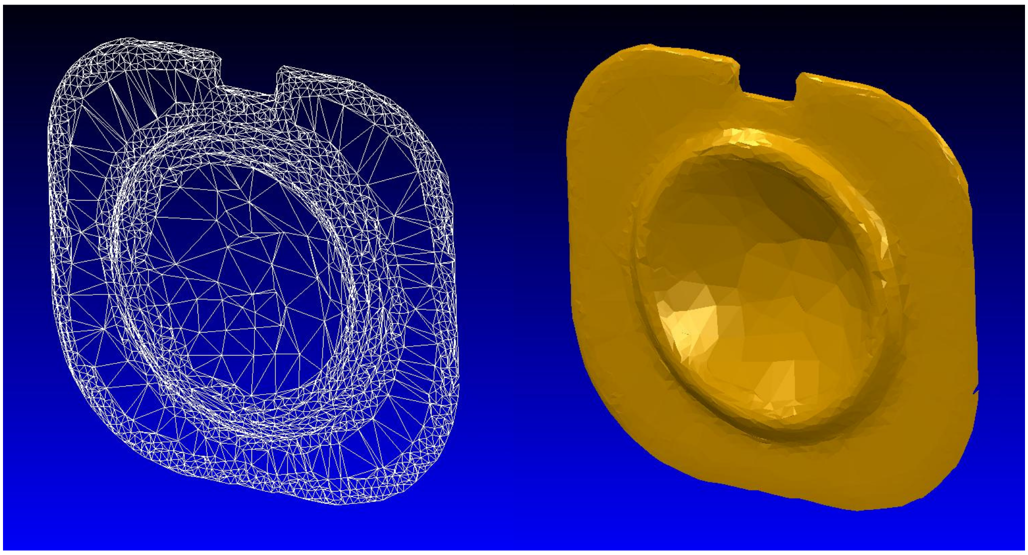

Fig. 2. *STL (Triangle mesh) filtered for FEM simulation of part deformation.*

After filtering the point cloud is usually interleaved by polygonal (triangle) mesh. A multi face interpretation of the solid is obtained. Size of mesh faces is different and it is given by the point cloud surface density. The bigger is the density the higher is the number of smaller faces. Created mesh can be exported from the scanning software. The most common is the STL (Stereo lithography) exchange format.

4. Scanned data in machining

Scanned data can be used in many different applications. But machining is an application, which is very sensitive on quality of scanned model. If triangle mesh model is directly used for machining, it does not give good surface of workpiece. Any error, e.g. gap, undercut, overlap or unfiltered noise in triangle mesh leads to unwanted machined surface discontinuity and lowering of precision of workpiece. To prevent above mentioned effects, STL model should be replaced by NURBS faces representation. The same NURBS faces that CAD/CAM software use in their modelling methods.

4.1 Converting triangle mesh to NURBS

Although the triangle mesh with proper density looks like a model created in CAD software (Fig. 3) and it can be handled like a model in CAD, edit options are limited. Despite the smooth appearance, the model is still created by triangle faces that are not „watertight" and tangentially connected. This can cause problems for example in tool path creation in CAM. The tool path is not a smooth curve but a set of straight connected lines. The machined surface will not be smooth (Fig. 4). That is one of the reasons why STL model is reworked in to a NURBS model [2].

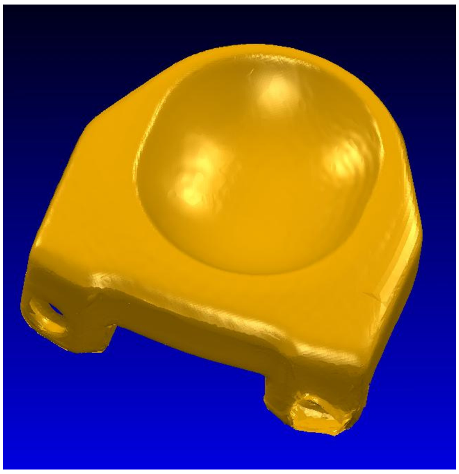

Fig. 3. *Unfiltered smoothed STL mesh.*

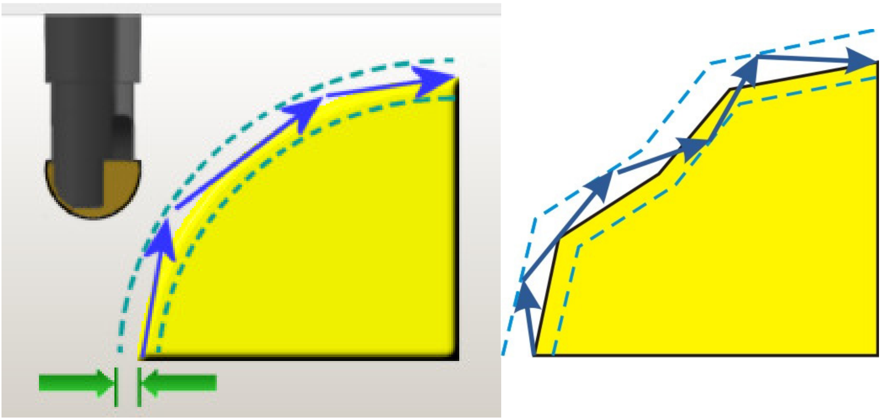

Fig. 4. *Tool path calculation principle (left – ideal model, right – scanned model) [2].*

Process of replacing STL model by NURBS faces is based on „lapping". The form of reconstructed solid is usually very complicated so that it cannot be covered by one smooth face. But it can be put together from partial faces – plates (patches) that are connected to each other.

The original STL surface is divided into regions similar to real shape. These regions, still presented by triangles, are interleaved by NURBS plates with defined number of control points. The NURBS face is computed by the software to provide the best STL surface interpolation. User can insert NURBS plates manually in order to repair small details unworkable by the software.

If a complete model is needed this can be a very long operation with high demands to software and operator's skills because it cannot be fully automated yet. Following paragraphs describes the most important issues, where automation doesn't give a good result yet and must be worked manually.

4.2. Missing surface error

Missing surface error is disadvantage of 3D scanning process. We can sort the error in two categories – missing surface due to some hardware limitation (Fig. 5) and missing surface due to software processing - gaps (Fig.6).
Situation in the figure 5 shows missing surface occurred due to hardware limitation of the scanning method. The corner (marked „A") on scanned part has got a smaller angle, than angle between camera and laser beam (Fig. 1), therefore the scanner cannot capture it. Letter B marks the case, when surface was not captured due to high reflectivity of the workpiece.

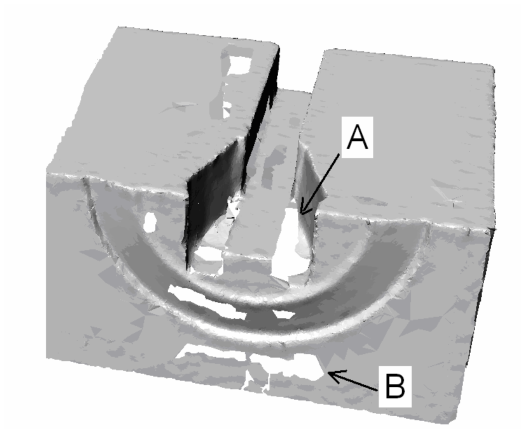

Fig. 5. *Examples of missing surface .*

Sometimes the automatic postprocessing of scanned data erases important point or blends different points into one. This error also appears at places where are some features sized similar to the resolution of the scanning head. E.g. corners, hole bottoms, small ribs.
This all can lead to "gap" appearance. The gap is a place where no face, no surface normal are created and you can see the inner side of the model. The gap width is usually close to the scanning resolution (approx. 0.05 mm) But if the CAM software will try to calculate tool path point in this specific point you will get a big error and bad machined surface.

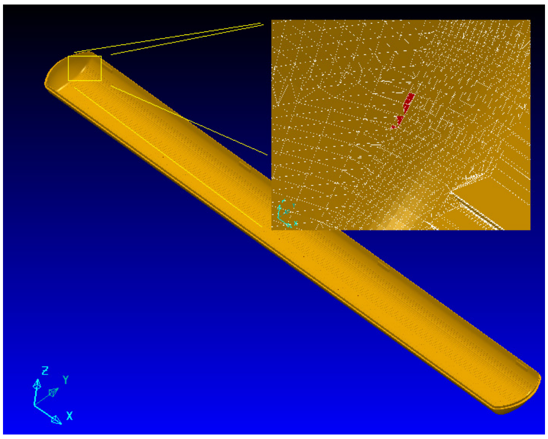

Fig. 6. *"gap" examples on scanned surface[2] .*

The picture (Fig 6.) shows an example of this error on a scanned light diffuser. The zoomed part shows a few missing faces in the corner. Through the missing faces you can see the red colour of the back surface of the model.
These errors can be corrected or lowered by the data postprocessing. Reverse engineering software has usually function, which can find and repair the gaps in whole mesh, but user must every time check if the gap was filled correctly.

4.3. Continuity of NURBS faces

The most important thing when finishing reconstruction of NURBS model is to check continuity of created plates. There is NURBS representation of scanned solid on fig. 8 created in reverse engineering software. The left one seems to be smooth enough to perform machining of this shape so that e.g. mould can be created. But after continuity analysis using zebra stripes some discontinuity is apparent.

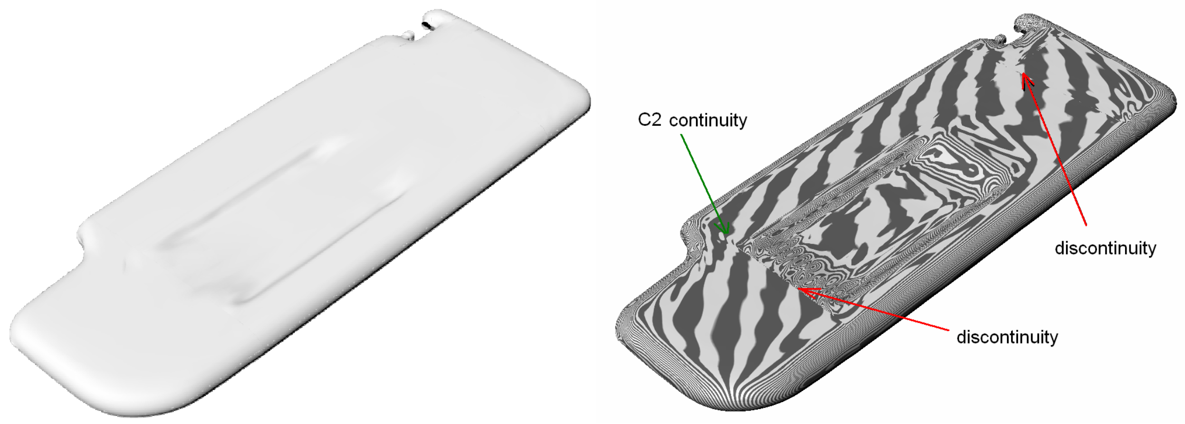

Fig. 8. *Continuity analysis.*

Software sets the continuity of the transition between NURBS patches, making them smooth and watertight. Although each NURBS plate exists individually, adjacent plates must join smoothly to define the entire shape. Otherwise, there may be holes or seams along the shared boundaries.

If the continuity between neighbour faces should be achieved, user must have on his mind that parameterization of adjacent patches must be the same (Fig. 9). Therefore is necessary to manually check every software created patch, if it has the same parameterization as its neighbours.

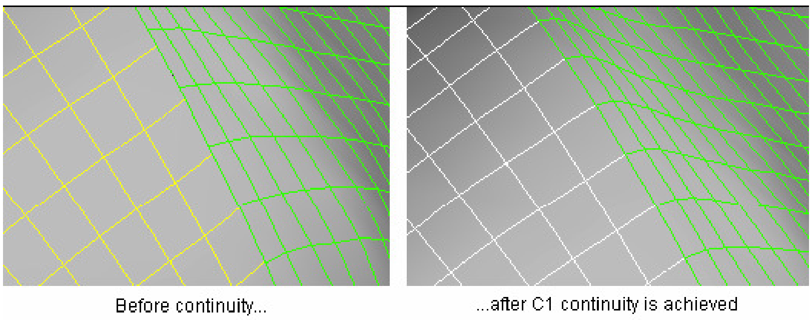

Fig. 9. *Continuity of NURBS patches .*

5. Conclusion

Laser scanning method is coming across wide range of applications in modern manufacturing and quality control. In metrology is primarily used for control or comparison of existing piece against computer model. Except quality control, laser scanner can be used for reverse engineering applications, where emphasis is placed namely on integrity of triangle mesh surface and continuity of NURBS plates. These two factors are very important in further data processing, as can be CNC machining. Application of laser scanning together with scanned data postprocessing can give a higher accuracy, bigger speed and smooth machining resulting in better machined parts.

Short title list

CNC – Computer Numerical Control
CMM – Coordinate Measuring Machine
RE – Reverse Engineering
CAD – Computer Aided Design
CAM – Computer Aided Manufacturing
NURBS – Non – Uniform Rational B-Spline
CL-data – Cutting Location data

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